radiation above the atmosphere at wave length 0.32μ. No such correlation is found for radiation after passing through the atmosphere above Tucson. Haze in the lower atmosphere usually is accompanied by somewhat lowered radiation values. In the practice of heliotherapy. it is important to recognize the probability of frequent intensity variations of considerable magnitude. Only a very rough prediction of radiation values on any given day can be made by reference to average values previously found. Accurate dosage can be determined only from radiation measurements made at the time of exposure of the patient.

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CHANGES IN THE SOLAR CONSTANT OF RADIATION

By Prof. Dr. FRANZ BAUR

[Staatl. Forschungsstelle für langfristige Witterungs-vorhersage, Frankfurt on the Main, Germany, February 14, 1932]

SYNOPSIS

In the first part (A) of this paper it is shown that even the latest solar constant observations of the Smithsonian Institution contains a 12-month period, and that its course is exactly the reverse of what it was before the alteration was made in the formula used for the determination of the transparency of the atmosphere. In the second part (B), the changes in the solar constant from 1919–1932, according to Abbot's measurements, are recorded against the sun-spot changes. It seems that the changes in the solar constant are neither parallel to nor opposed to those of the sun spots. But the highest values of the solar constant appear chiefly to occur *between* the maxima and minima of sun spots, whilst the lowest values occur near the extremes of sun-spot activity. An attempt is made to explain this. In the third part (C) of the work it is pointed out that a similar relationship exists between certain weather phenomena and sun spots.

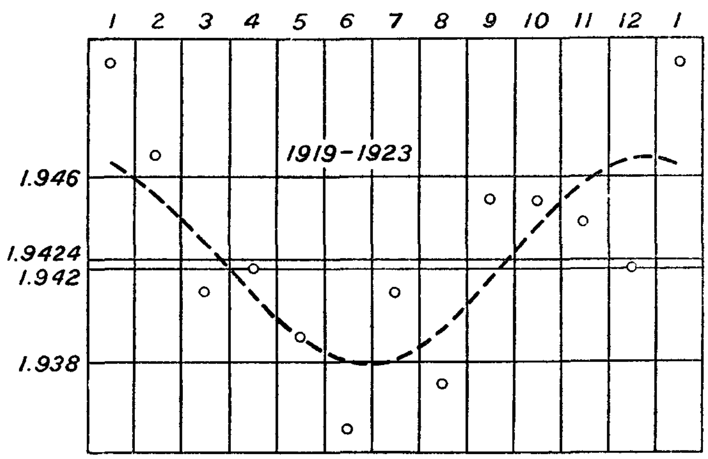

FIGURE 1.—Five-year averages of the mean monthly values of the solar constant. 1919–1923. Circles indicate averages of observed values; the dotted line is a sign curve of approximate fit through these values

A. THE ANNUAL VARIATION OF ABBOT'S SOLAR CONSTANT

In the following, only the large changes of the solar constant, as expressed in the monthly means, are considered.

C. F. Marvin[1] proved, as is known, that in the monthly means of the values of the solar constant of 1919 to July, 1924 (according to Abbot and his fellow workers), a definite 12-month periodicity occurs. From this it must be concluded that the values estimated by means of a so-called "short method" (in use since 1919) are also *still affected by terrestrial influences*. Since Abbot, however, has reckoned[2] the transparency of the atmosphere, using his short method (since 1925 according to a new formula), the question arises as to whether the disturbing effects of terrestrial conditions on the measurements thus have been eliminated.

The recent publication[3] of the monthly means of the solar constant values from 1919 to 1930 does not show whether or not the former values have been adapted to the new formula for the determination of the transparency of the atmosphere. But Abbot says in this work that the best values are those from January, 1924, onward. He evidently assumes that the beginning of the year 1924 marks a break in the homogeneity of the measurements. I examined therefore the annual variation of the solar constant separately for the periods 1919–1923 and 1924–1930. The result is shown in Figures 1 and 2. It is seen that in the period 1924–1930 an annual variation also occurs which can readily be shown by a sine curve. But the course of the annual variation in the second period of time is exactly the reverse of that in the first.

On the other hand, it also becomes apparent, from the comparison of Figures 1 and 2, that the amplitude of the annual changes in Abbot's solar constant since the use of the new formula has become smaller. Of course, this lessening of the annual amplitude is probably chiefly caused by the standard deviation of the monthly means in the solar constant values in the period 1924–1930, being in itself smaller than that in the period 1919–1923.

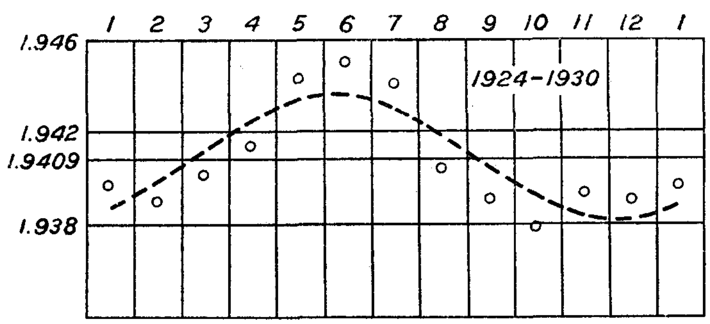

FIGURE 2.—Seven-year averages of the mean monthly values of the solar constant, 1924–1930. Circles indicate averages of observed values; the dotted line is a sign curve of approximate fit through these values

In the following summary the size of the annual change, expressed by means of the difference between the mean value of the six months from September to February and that of the six months from March to August, is compared with the size of the standard deviation in the corresponding period of time as well as with the presumably accidental annual change in the relative numbers of sun spots.

[1] C. F. Marvin, Monthly Weather Review 53 (1925), p. 301.

[2] C. G. Abbot, Gerlands Beiträge zur Geophysik 16, 1927, pp. 362 and 363.

[3] Smithsonian Misc. Collect. 85, No. 1. Washington 1931.

The amount of the difference stated was:

Period	Solar constant	Sun spots
1919–1923	0.007 gr cal cm^{-2} min^{-1} = $0.576\sigma'$	4.9 = 0.20 σ'_r.
1924–1930	0.003 gr cal cm^{-2} min^{-1} = $0.490\sigma''$	3.8 = 0.15 σ''_r.

σ' and σ'_r in the above stand for the standard deviations of the monthly means of the solar constant values and sun-spot relative numbers, respectively, in the period 1919–1923; σ'' and σ''_r for the corresponding standard deviations in the period 1924–1930.

It is apparent from the above table that the annual change in the solar constant is considerably greater than that in the sun-spot relative numbers. (The average annual variation of sun-spot relative numbers is, by the way, also much less regular than that of the solar constant.)

The result of this investigation is that even in the latest solar-constant measurements of Abbot and his associates, the earth also plays a part, though this effect is somewhat smaller, since the use of a new empirical relation for the determination of the transparency of the atmosphere. The fact that the annual variation of the solar constant which still occurs after the use of the new formula is in inverse ratio to the annual variation of the transparency of the atmosphere, encourages us to hope that by corresponding theoretical and empirical investigations we shall soon so improve the formulæ required that no systematic annual variation will any longer exist.

B. SOLAR CONSTANT AND SUN SPOTS

The fact that terrestrial influences affect solar-constant measurements reduces the value of the comparison of these measurements with the course of the sun spots, since we do not know exactly what part the actual changes of the solar constant have in the observed variations.

Still, such a comparison with the new solar-constant values, if one deals with them in a suitable manner, has considerably more meaning than was the case with the values obtained according to the old Langley method (before 1919), which were affected in a much higher degree by terrestrial influences. Since the difference, between September to February and March to August amounts to only a fraction of the standard deviation of the monthly means of the solar constant values, there must, therefore, be contained in these a considerable part of the actual changes of the solar constant.[4] If one does not wish to make use at once of annual means, the annual variation can be eliminated very simply by forming half-yearly means from January to June and from July to December. The average difference between I to VI and VII to XII, in the period 1919 till 1923, as well as 1924–1930, was less than 0.0005 gr cal cm^{-2} min^{-1}.

The changes of the half-yearly means of the solar constant from 1919–1931 are set over, in Figure 3, against the half-yearly means of the sun-spot relative numbers for the same period. From this diagram it is obvious that *no linear relationship* exists between the solar constant and sun spots.

Numerically this can be seen from the correlation coefficient between the monthly means of the solar constant and those of the contemporaneous sunspot relative numbers. This correlation coefficient is for the whole period 1919–1930, $+0.11 \pm 0.08$, but for the period 1924–1930, -0.23 ± 0.10. (The given errors are mean errors.) The same correlation coefficients are obtained if one inserts in place of the observed monthly means of the solar constant values, monthly means corrected for annual variation. It is apparent from the smallness of the correlation coefficients, together with the fact that the sign of the coefficient in the part period is different from that in the whole, that there is no linear relationship between the two quantities.

On the other hand, from Figure 3 there seems to be a connection in the sense that the solar constant shows values *below normal* both near a sun-spot minimum and a

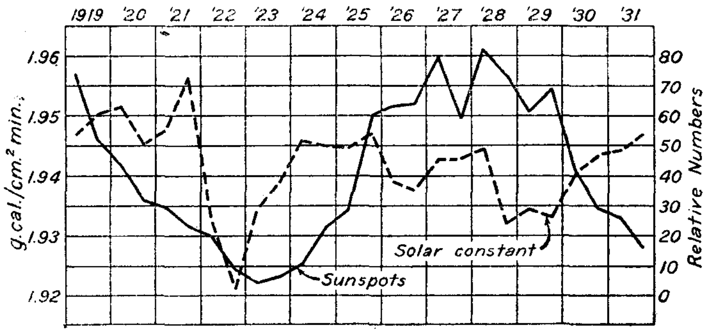

FIGURE 3.—Values of the half-yearly means of the sun-spot relative numbers of Abbot's solar constant, 1919–1931

sun-spot maximum, and *highest values in the years between these extremes*. The small secondary maximum in the year 1927 and in the first half of 1928 probably is to be explained by the fact that the intensity of the last sun-spot maximum was very slight, and the maximum had no single highest point. Even in the half-yearly means of the sun-spot relative numbers, three maxima are clearly perceptible.

Whether the lowest values of the solar constant really occur *as a rule* near the sun-spot extremes, and the highest values *between* them, or whether this occurrence belongs just to the period 1919–1931, can be determined only by many more years of observations of the solar constant.

Should further observations prove the connection, supposed to exist from the evidence of the measurements of 1919–1931, to be an actual one, then the following explanation could be given with the help of some plausible assumptions.

Let us assume solar radiation into space in all heliographic latitudes and longitudes to be equal, then the solar constant I_0 is proportional to the radiation A_s issuing from the sun as a whole.[5] This emission A_s stands to the radiation A_p of the photosphere in the relation

$$A_s = A_p\ (1-\eta) \tag{1}$$

in which η is that fraction of the photospheric radiation which returns from the solar atmosphere to the photosphere.[6]

It can readily be supposed that the photospheric radiation in general increases with the increase of sun-spot activity. The fact that the matter composing the sun spots is cooler than that of the undisturbed photosphere is not opposed to this supposition, for the sun-spots comprise only a very small part of the solar surface. It is however highly probable that during intense activity

[4] The following may serve for comparison. If the change of a quantity in time can be expressed by means of a pure sine oscillation with a period of one year in length, then the difference between the mean value of the 6 highest and 6 lowest monthly means is 1.8 times as great as the standard deviation of the monthly means.

[5] The supposition is, of course, in reality wrong. It was only made for the sake of simplicity. The thing itself is not essentially changed through the presence of local differences; only in this case A_s and A_s must be regarded as sums over all the surface elements of that half of the sun turned toward the earth.

[6] Cf. F. *Baur*, "Zeitschrift für Astrophysik," vol. 3, p. 29.

matter is brought to the radiating surface from the depths of the sun in quicker succession, and therefore the surface is on the whole hotter than at the time of less intense sun-spot activity. This idea is supported by the fact that increasing frequency of the hot sun faculae accompanies increasing sun-spot activity. (The correlation coefficient of the annual means of the sun-spot relative numbers with the simultaneous sun faculæ relative numbers in the period 1887–1930 amounts to $+0.89 \pm 0.03$). If this be so, then a linear stochastic relation between A_p and the sun-spot relative numbers f can be supposed, as follows:

$$\mathsf{E}\ (A_p) = a_1 + a_2 f \tag{2}$$

in which a_1 and a_2 are positive.[7]

Almost parallel with the sun spots however, the calcium flocculi, as well as the bright and dark hydrogen flocculi, also change in quantity and intensity. In particular, the correlation coefficient of the monthly means of the character figures of the latter with the simultaneous sun-spot relative numbers, amounts, in the period January, 1928, to September, 1931, to $+0.74 \pm 0.07$. We shall hardly be wrong if we draw the conclusion that there is also a dependency of η on the sun spots in the sense that η increases also with increasing solar activity. If this connection is also linear, then

$$\mathsf{E}\ (\eta) = b_1 + b_2 f_1 \tag{3}$$

in which again b_1 and b_2 are positive, and, further, because $\eta < 1$, also $b_1 < 1$ and $b_2 \ll 1$.

From (1), (2), and (3) it follows that

$$\mathsf{E}\ (A_s) = c_1 + c_2 f - c_3 f^2$$

and therefore

$$\mathsf{E}\ (I_0) = C_1 + C_2 f - C_3 f^2 \tag{4}$$

The dependency of the mathematical expectation of the solar constant I_0 on f can also be shown by a parabola. If $\frac{a_1}{a_2} < \frac{1-b_1}{b_2}$ which since $b_2 \ll 1$ is easily possible, then C_2 is positive, and then the apex of the parabola lies *between* $f=0$ and $f=\max$.

The phenomenon that the lowest values of the solar constant occur in general with the extremes of the solar activity, the highest values on the contrary in between, can therefore be explained by the two suppositions that A_p and also η increase linearly *with* the sun spots. If the stochastic relationships (2) and (3) are not linear, then the right-hand side of (4) becomes a parabola of a higher order. Then several maxima of I_0 can lie between $f=0$ and $f=\max$.

C. SUN SPOTS, SOLAR CONSTANT, AND WEATHER PHENOMENA

For the actuality of the supposed approximately parabolic relationship between sun spots and solar constant, that is, that this relationship is not peculiar to the period 1919–1931 but is an essential property of the sun-spot-solar constant phenomenon complex, regarded as a 2-dimensioned collective object, we have the evidence that extremes of the same kind of numerous *meteorological phenomena* are to be found near the sun-spot extremes, and the opposed (but among themselves also of the same kind) extremes between, and they are of such a kind that these changes could be explained by the occurrence of the lowest values of the solar constant at the time of the sun-spot extremes and of the highest values in the years between. I shall deal with this in greater detail in an article in the "Zeitschrift für angewandte Meteorologie." In the following, only two of the above-mentioned phenomena from the history of the weather of Central Europe will be briefly dealt with.

If of the severe winters of Central Europe of the last 200 years, we consider the 10 severest, characterized by their mean temperature in Berlin of at least 4° C. below the average long period value,[8] we find that they are distributed over two narrow sections of the sun-spot cycle—of from 0.2 year before to 1.3 years after the maximum and of from 0.7 year before to 1.7 years after the minimum of sun spots. If the probability of the occurrence of a very severe winter with a negative temperature deviation of at least 4° C. in Berlin for all parts of a sun-spot cycle, were equally great, then the probability that 10 such winters would fall quite accidentally on the narrow sections referred to of altogether only 3.9 years, would be

$$W = \left(\frac{3.9}{11.1}\right)^{10}$$

This probability is of the order of magnitude 10^{-5}, so that we could suppose that the observed distribution of the ten severest winters within the sunspot cycle is *not accidental* and that therefore the probability of the occurrence of this sort of winter is *not* equally great in all parts of the sun-spot cycle.

Of course, there have also been severe winters beyond the neighbourhood of sun-spot extremes, and mild winters within, since the occurrence of severe or mild winters does not alone depend on the solar constant, but very considerably on the preceding *terrestrial* weather conditions. It seems, however, the necessary terrestrial conditions being fulfilled, a winter in Central Europe will be *specially* severe if it falls at the same time in the proximity of a sun-spot extreme, that is to say, if, according to our supposition, the solar energy received by the earth is *below normal*.

This can be explained by the fact that, other conditions being equal, the subtropical high-pressure belt is less strongly developed and extends less further polewards with solar constant below normal. Thus arises the tendency to the occurrence of a relatively low pressure near the Azores and in southwest Europe, which favors a flow of cold air from North Russia towards Central Europe. Besides this, the actual deficit in insolation also adds to an increase of the cold.

If we assume that the solar constant in the years lying *between* the sun-spot extremes is increased, then the fact can also be explained that by taking the average of all the years in the 100-year period 1831–1930, occupying the same position within the sun-spot cycle, two distinct maximum values of *summer atmospheric pressure* result and, similarly, two distinct minimum values of the quantities of *summer precipitation* for Central Europe, two years before the maximum and minimum of the sun spots, respectively (fig. 4). Other conditions being equal, an increase in the solar constant must create a bulge polewards of the subtropical high-pressure belt, especially in the summer months, in the geographical longitudes which in the Tropics and subtropics have the largest land masses. To such displacements of the subtropical high-pressure

[7] Regarding the meaning of the mathematical symbol E, see Baur, F. Korrelationsrechung, p. 12. Leipsic and Berlin.

[8] These winters are: 1739–40, 1783–84, 1788–89, 1798–99, 1799–1800, 1804–5, 1822–23, 1829–30, 1837–38, 1928–29.

belt, Central Europe chiefly owes its dry summers, whilst without them the geographical conditions of Central Europe would favor cool and wet summers.

There are naturally here also many exceptions, since foregoing terrestrial conditions also play an important part in the character of summer weather. It is, however, worthy of note that of the 16 summers of the period 1831–1930 which show, on the average, out of 25 Central European stations a deficit of precipitation of over 50 mm, not a single one fell in the two parts of the sun-spot cycle in which, without exception, the 10 severest winters of North Germany occurred. Fifteen of the 16 very dry summers of the period mentioned fell in the two narrow sections of from 2.6 to 0.6 year *before* a maximum and of from 2.2 to 1 year *before* the minimum of sun spots. The probability that the 15 very dry summers fell quite accidentally in these sections out of altogether 3.2 years, is:

$$W=16\left(\frac{3.2}{11.1}\right)^{15}\frac{7.9}{11.1}$$

This probability is of the order of magnitude 10^{-7}. *That these striking facts have hitherto remained unrecognized* is because almost all investigators who have dealt with the relations between solar phenomena and terrestrial weather phenomena have sought after contrasts between years rich and poor in sun spots, respectively. The estimations of the solar constant hitherto obtained render it apparent, that little is to be gained at least for the temperate zone by seeking for such contrasts. On the other hand, it is very important for the understanding and explanation of weather phenomena, on the whole, to show that in the case of many meteorological elements, two maxima and two minima occur within the sun-spot cycle corresponding to the two highest and the two lowest values of the solar constant within the sun-spot cycle.

In view of the foregoing facts and the results arrived at by observations of the solar constant, it is curious that in the Tropics a far-reaching parallelism exists between the course of the temperature and the sun spots. The correlation coefficient of the annual mean of the temperature of $\frac{1}{2}$ (Apia+Colombo), together with the succeeding annual mean of the sun-spot relative numbers taken from July to June, amount in the period 1890–1920 to -0.64 ± 0.10. Since there is between solar constant and sun spots no linear connection, as we have seen, we must, to explain this phenomenon, assume that it comes to pass *indirectly*, in that the emission of the sun changes in a limited, perhaps very small spectral region parallel or opposite to the sun spots, and this changes the transparency of the terrestrial atmosphere.

ADDENDA

After the conclusion of the foregoing paper, Doctor Abbot pointed out to me that he had already, in 1925, expressed the view that the 12-month periodicity of the solar constant shown by Marvin did not really exist, but was in truth an 11-month period.

Even if no physical reasons can be given for the occurrence of an 11-month period, yet the possibility of such can not be disputed off-hand. I have made therefore the following investigation in order to settle the question whether the annual variation which shows itself in the measurements of the solar constant is in reality a 12- or 11-month period.

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I divided the whole period under investigation (1919–1930) into 4 equal parts, each containing 36 monthly mean values of the solar constant, and reckoned for each the amplitude and the phase of a 12-month trial period by the Fourier method. Then I divided the period 1919–1929 into 4 equal parts, each with 33 monthly mean values, and reckoned for these in similar manner the amplitude and phase of an 11-month period. I obtained the following amplitudes r $\left(\text{in } \frac{1}{1{,}000}\text{'s gr cal}\right)$ and phases ζ:

12-month period			11-month period		
	r	ζ		r	ζ
		° ′			° ′
1919–1921	4.4	92 44	I 1919–IX 1921	4.0	14 0
1922–1924	2.9	65 18	X 1921–VI 1924	4.3	353 15
1925–1927	2.9	245 51	VII 1924–III 1927	3.7	354 23
1928–1930	3.6	313 2	IV 1927–XII 1929	4.6	359 18

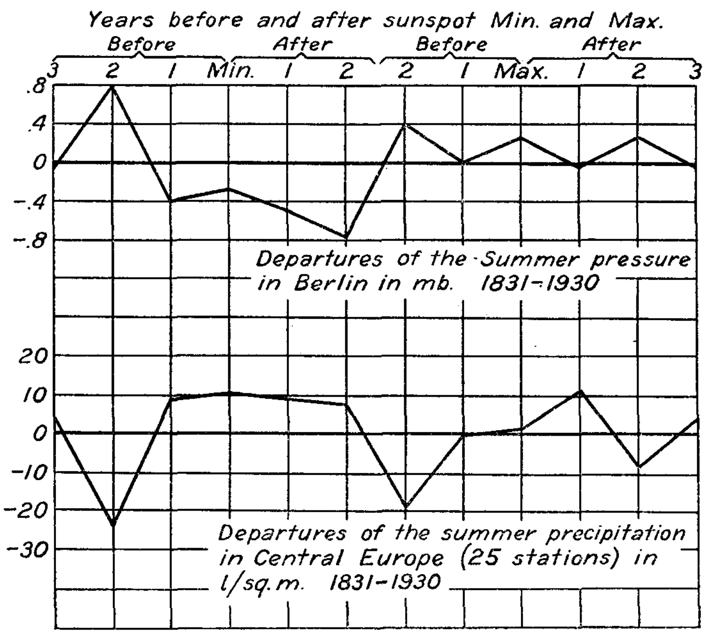

FIGURE 4.—Average values of summer atmospheric pressure (in millibars) and precipitation in Central Europe during the sun-spot cycle. (Regarding the construction of the curves, see Astrophysikalische Zeitschrift, vol. 4, No. 3, 1932. The curves are *not* smoothed)

The fact that the amplitudes of the 11-month period are for the most part larger than those of the 12-month period, as also the further fact that the phases of the 11-month period are practically of equal size (especially those of the last three periods) supports the theory of the existence of a true 11-month period. If such a period existed, then by taking only a few years, a 12-month period might, it is true, seem to exist, and, the reversal of the course of the annual variation in two succeeding periods of from 5 to 7 years, as set forth in section A of the foregoing paper, could be explained. Then, however, the phase of a trial 12-month period (in absence of other changes) would have to increase equally from one subperiod to the next. But that, as the above figures show, is not at all the case. The irregularities may possibly be explained in part by the occurrence of other changes. But the fact that the difference of the phase between the periods 1922–1924 and 1925–1927 amounts to almost exactly 180°, appears, however, to indicate a true 12-month period, which, as a result of the already-mentioned alteration of the formula used for the determination of the transparency of the atmosphere, was reversed in its course.

Summarizing these considerations, we can say that from the data at hand it can not be concluded with certainty that an 11-month period exists. For this the material available is too scanty. So long, however, as the 11-month period can not with certainty be proved, it is more reasonable to interpret the facts of observation as an annual variation resulting from terrestrial influences, where the discontinuity of 1925 is caused by the alteration in the reckonlng of the transparency, than to assume an 11-month period for which there is no physical explanation whatsoever.

THE CHANGE OF HUMIDITY INCIDENT TO A THUNDERSTORM

By W. J. HUMPHREYS

Anyone who has seen sheets of rain in a thunderstorm vanish wholly before reaching the surface, as they often do in an arid region, and who also has experienced the drop in temperature that accompanies the rain when it does fall to the ground, is quite ready to believe that the relative humidity must increase with the onset of such a shower. And this is just what does happen as the books tell us and the records show.

But how does the absolute humidity, more important than relative humidity in some respects, change with the progress of the storm? The answer to that question, which has been raised in connection with certain lightning-protection problems, is not in the books, nor in the journals either, so far as I could find in a brief search. Recourse therefore was had to original data. Mr. G. E. Dunn, of the forecast division of the Weather Bureau, selected for me a number of typical heat thunderstorms and an equal number of cold-front storms. Then the automatic humidity record of each of these, extending from before its beginning to after its close, was looked up by the division of climatology, Mr. J. B. Kincer in charge.

It was found that (1) in heat thunderstorms the absolute humidity *increases* with the onset of the rain by, say, 15 to 20 per cent, or, roughly, 1 grain of vapor per cubic foot, or 2¼ grams per cubic meter, and (2) that in cold-front thunderstorms the absolute humidity *decreases* in more or less the same proportion, that is, in the order of 1 grain of vapor per cubic foot.

The obvious explanations of these phenomena are:

a. In the case of the heat thunderstorm, since the absolute humidity of the air is approximately the same on all sides of it, therefore the evaporation of the falling rain necessarily increases the vapor density, as does also the contraction due to decrease of temperature, above that either before the onset of the shower or a while after its passage.

b. The distribution of the absolute humidity about the cold-front thunderstorm, however, is quite unequal. It is much greater in the warm air in front of the storm than it is in the cold air to the rear. Here, although the absolute humidity of the air through which the rain is falling necessarily is increased, by virtue of the evaporation that occurs and the decrease of temperature, this gain ordinarily is not enough to raise the vapor content of the oncoming dry air up to, much less above, that of the warm humid air in front of the squall. Hence, in the cold-front thunderstorm the absolute humidity generally decreases with the onset and progress of the storm.

WEATHER TYPES OF THE NORTHEAST PACIFIC OCEAN AS RELATED TO THE WEATHER OF THE NORTH PACIFIC COAST

By THOMAS R. REED

[Weather Bureau, San Francisco, Calif., 1932]

The weather types of the northeast Pacific Ocean are so closely related to the general wind systems of that region that any discussion of them must be predicated on an understanding of what these wind systems normally are and the changes in weather types that changes or disruptions in the normal wind systems bring about. These wind systems correspond in a general way to those found in similar latitudes in the North Atlantic Ocean and may be inferred from the so-called centers of action with which they are associated. One of these centers of action is the semipermanent high which is usually at its maximum between northern California and Hawaii, and the other is the semipermanent low usually somewhere to the northwestward of it. The low reaches its maximum development in winter when the wind systems which accompany it are strongest. The high reaches its maximum in summer due in part to the accumulation of air ejected from the continents of the northern hemihemisphere at that time of year.

It is sometimes convenient to refer to these so-called centers of action as though they were causative and responsible for the wind systems about them, but for practical purposes such as weather forecasting or the analysis of weather types it is helpful to recognize them more often as effect than cause and to see in them the indirect but substantial evidence of the set and strength of the accompanying wind systems. In the words of Sir Napier Shaw—

> Instead of looking to the centers of high and low pressure as controlling powers, I should propose to regard them as created by the distribution of currents which they have been supposed to control. * * * Thus in the free air low pressure and high pressure, depression and anticyclone, are the marginal effects of the flow of an air current in order to adjust the gradient to the current; the particular shape and intensity of the low and high are conditioned by the distribution of currents in the field.[1]

When the high is of ordinary or more than ordinary strength, the orientation of its major axis is the best clue to the classification of the prevalent weather type. When the high is insignificant, the predominant set of the isobars in the low has to be relied on for this purpose. Similar logic governs the interpretation of the weather chart in either case, for whether we are looking at the axis of the high or, in its absence, at the general trend of isobars in the low, we are interpreting the pressure situation which

[1] Quarterly Journal of the Royal Meteorological Society, Oct. 1931, pp. 460, 463.